High Data Volume Readout via Lasercom As An Enabler for Balloon-Based Science

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Outline

- **Intro to balloon comm and lasercom**
- **Present successful lasercom systems**
- **Possibilities for balloon lasercom**

Present RF Balloon Communications Connectivities

Continuous coverage at arbitrary position requires an orbiting relay

GEO relay (TDRSS)

(essentially) continuous relay (up to ~150 kbps)

Relay service also available using pLEOs: Iridium (~800 km) or Starlink (~550 km)

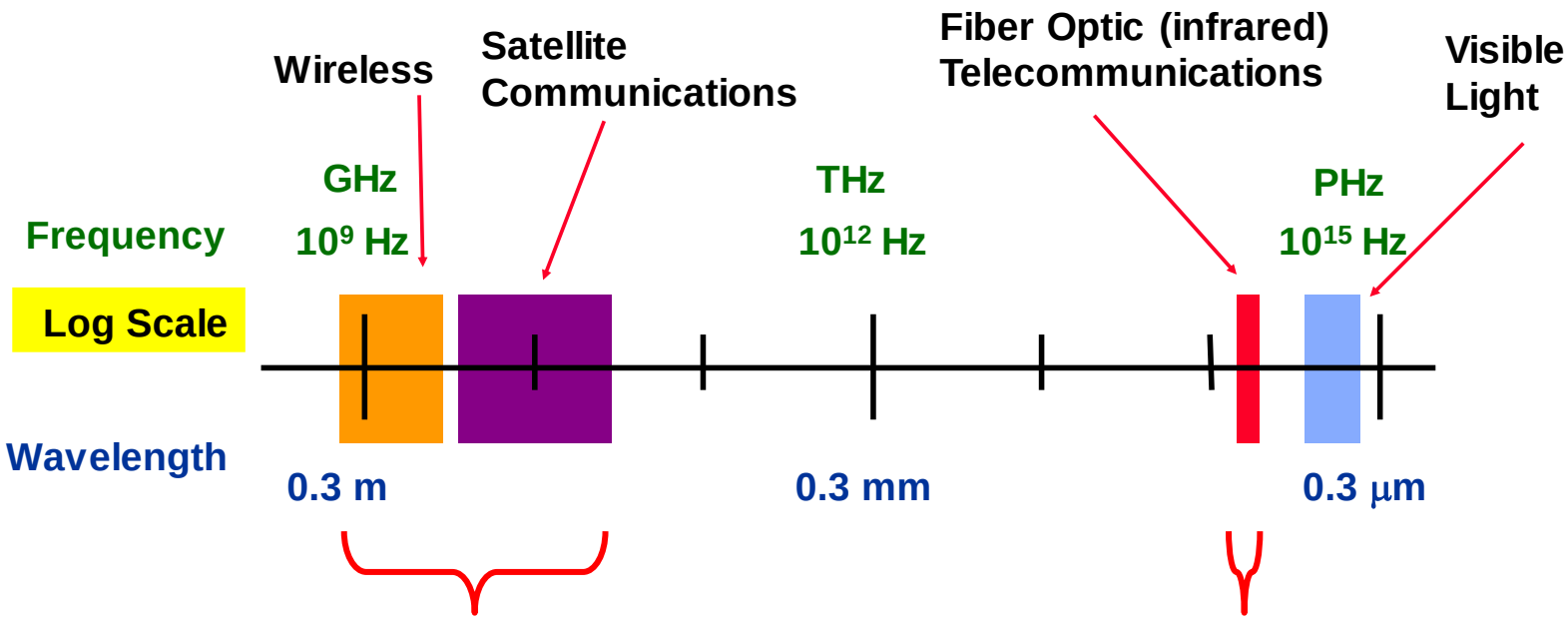
Direct downlink (Few 100 kbps to few Mbps)

When have line of sight to ground terminal

Question: Could optical technologies be useful in either of these architectures?

NASA

The Optical Bands



Entire RF bands up to few Ghz wide
Highly congested
Requires frequency allocation – FCC, ITU...
User designations up to hundreds Mhz

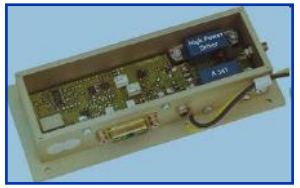
Fiber telecom band > 12 Thz
Unregulated
Fiber telecom users 50-100 Ghz

Potential optical bands
(>2800 Thz)

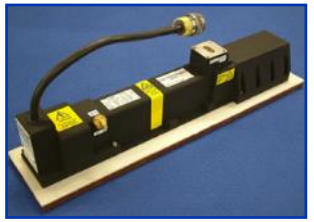
Also note:

1. A telescope is the antenna in an optical system
2. Because of the much shorter wavelength
   - Beams are *much* narrower than in RF
   - Power is much more efficiently transferred
3. The wide bandwidth plus the transmission capability means "lasercom" can transmit huge amounts of data

Parts of a Free-Space Communications System – RF



RF Osc



TWTA

Antenna 1'-50'

Digital Processor

Modulator

Amp

RF Waveguide

Diplexer

2 slightly frequency-offset RF carriers

Digital Back End

Demod

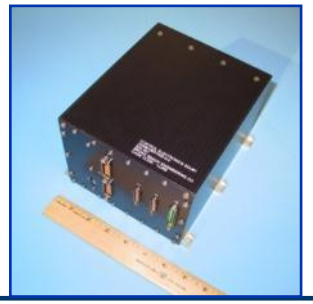
Receiver Front End

RF (Local) Osc

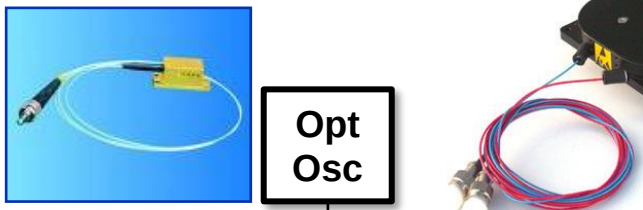
Steering Actuator

Steering Control

Many of these parts may be miniaturized and/or integrated

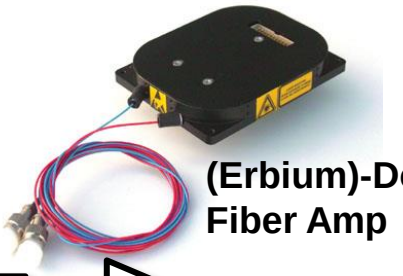


Parts of a Free-Space Communications System - Optical



Diode Laser

Opt Osc



(Erbium)-Doped Fiber Amp

Telescope 3" – 36"

Digital Processor

Modulator

EDFA

Offset (Point-Ahead) Steering

2 slightly wavelength-offset optical carriers

Single Mode Fiber

Diplexer

Digital Back End

Demod

Receiver Front End

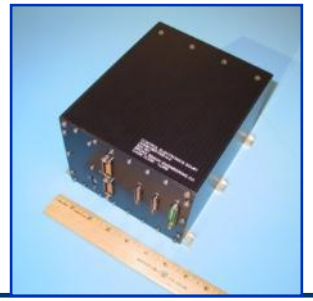
Opt (Local) Osc

Pt/Trk Actuator

Other Stabilization Devices

PAT Control

Many of these parts may be miniaturized and/or integrated

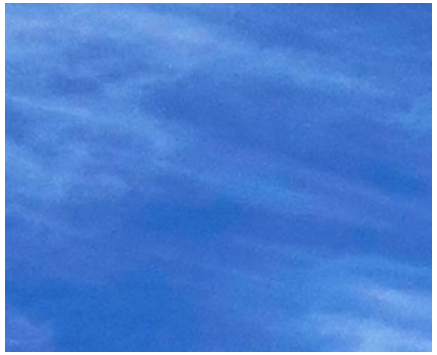


Various types of receiver/demods

Readiness of Lasercom

- **The fiber telecom industry**
  - **Has developed lasers, detectors, modulators, controls, etc**
  - **Can transmit many Tbits/sec in a single fiber**
- **After over 40 years of development, the free-space lasercom industry now understands all technical facets of operating in the optical bands**
  - **Pointing and stabilizing the narrow beams**
  - **Efficient signaling**
  - **Ability to use telecom-class, fiber-based transmit and receive components behind telescopes providing the transmission**
  - **Ability to transmit and receive through turbulent atmosphere**

Free-Space Lasercom Requires Cloud-Free Line of Sight



Wispy
- **Few dB loss**
- **Can design in extra margin**

Intermittent links
- **In-band data-flow control, such as**
  - **ARQ**
  - **DTN**

Complete blockage
- **Switch to alternate receiver with clear LOS, or**
- **Store and wait until there is a clear LOS**

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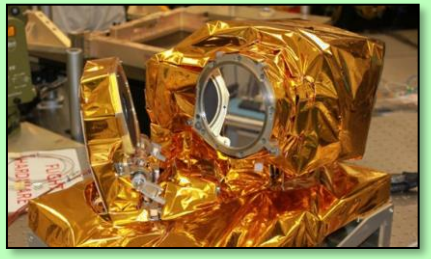
Recent and Ongoing Space Lasercom

Lunar Laser Comm Demo (LLCD) on LADEE (NASA 2013)

Moon-to-Earth comm
at 622 Mbps

Uplink at 20 Mbps

Space Terminal

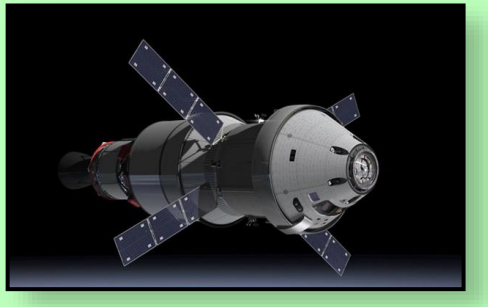


10-cm gimballed aperture
0.5 W eyesafe laser
Fiber-coupled modem

Ground Terminal

80-cm = 4@40 cm
Multi-mode fiber-coupled
Photon-ctg detectors
4@ eyesafe 10-W uplinks

Lasercom on ORION Crewed vehicle (NASA 2024)



Moon-to-Earth comm
at 80-250 Mbps

Uplink at 20 Mbps

Space Terminal

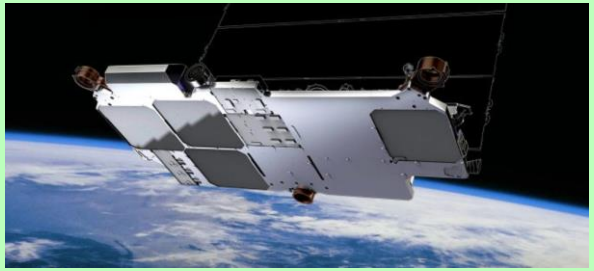
10-cm gimballed aperture
1 W eyesafe laser
Fiber-coupled modem

Ground Terminal

Single 40-cm
Multi-mode fiber-coupled
Photon-ctg detectors
4@ eyesafe 10-W uplinks

Commercial Space Lasercom Systems

EDRS (TESAT, Ge.) – space lasercom systems since 2014
– LEO-to-GEO (terminals for both ends)
– Gbps-class



Starlink (SpaceX) – OISL (optical intersatellite links)
– LEO – to – LEO
– 100 Gbps-class

Kuiper (Amazon) – OISL (optical intersatellite links)
– LEO – to – LEO
– 100 Gbps-class

Directly Relevant Ongoing Space Lasercom Systems

Laser Comm Relay Demo (LCRD) at GEO
ILLUMA-T on ISS
(NASA 2021/2023)

GEO relay

"User" terminal
recently installed on ISS

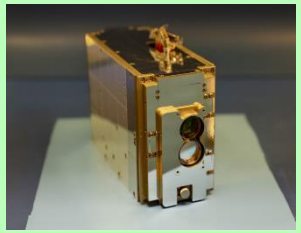
Ground support

Continuous
connections at 1.25
Gbps

TeraByte InfraRed Delivery (TBIRD)
(NASA 2022-3)

LEO-to-ground burst-mode comm at 200 Gbps
Low-rate uplink beacon & commands

40-100-cm ground
telescope



Multi-TB solid-state memory
Based on fiber-telecom modem
Capability demonstrated on 6-U
cubesat

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Possible Connectivities in Optical – I
Continuous

Optical GEO Relay

Examples:
LCRD (NASA)
EDRS (TESAT)

(essentially) continuous relay

Example:

- **10-cm (4-inch) balloon-based terminal**
- **10-15 cm GEO receiver telescope**
- **1-5 -W amplifier**

- **1-1.25 Gbps continuous**
- **(planned up to 10 Gbps)**

Optical or Radio Ground Station

- **GEO relay infrastructure still young and small**
- **Long link means balloon terminal must be large and expensive**

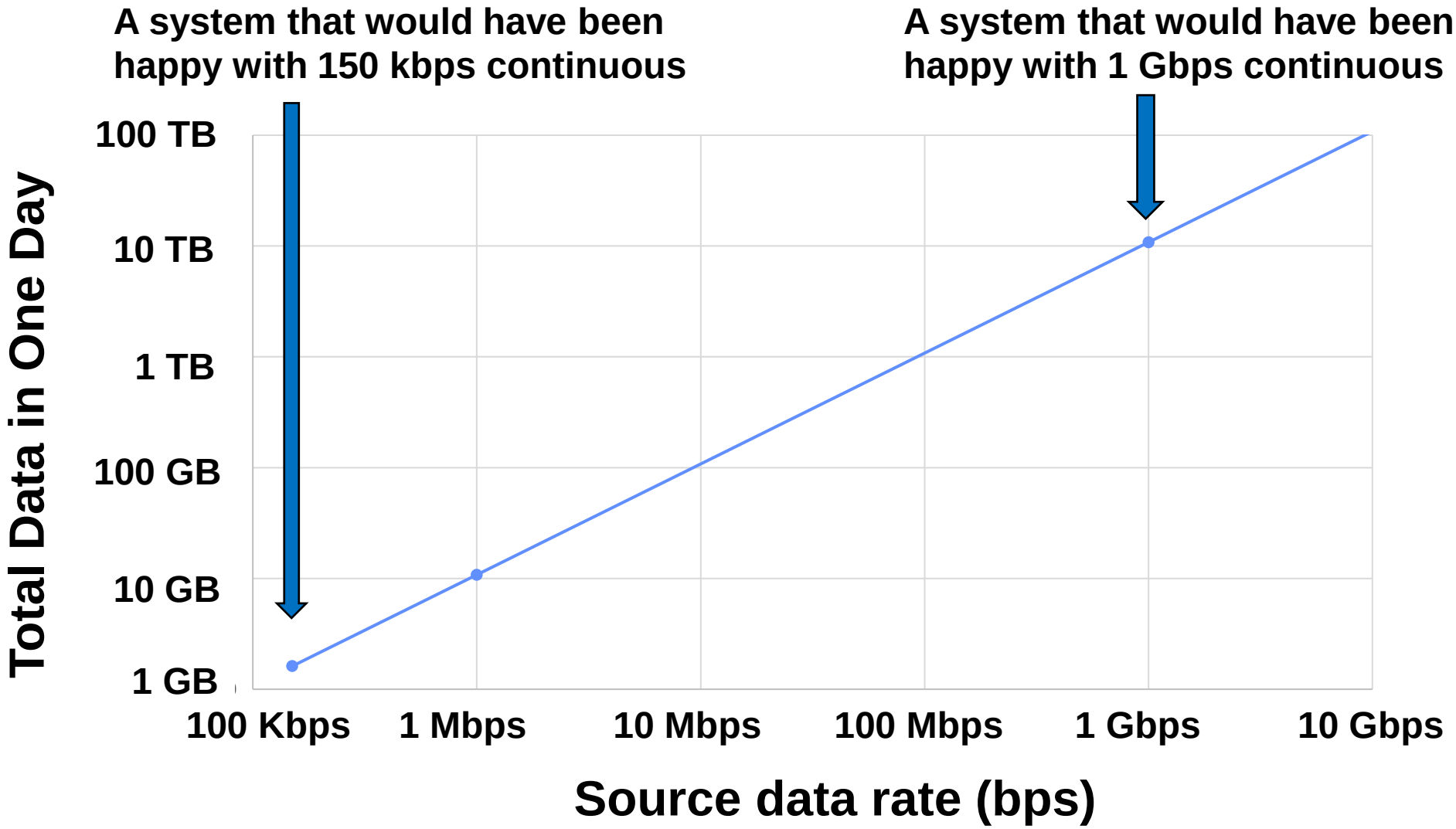
Notes on Store and Forward for Balloon Missions

- In survey, some users were happy to wait one or several days or even weeks for the measurement data

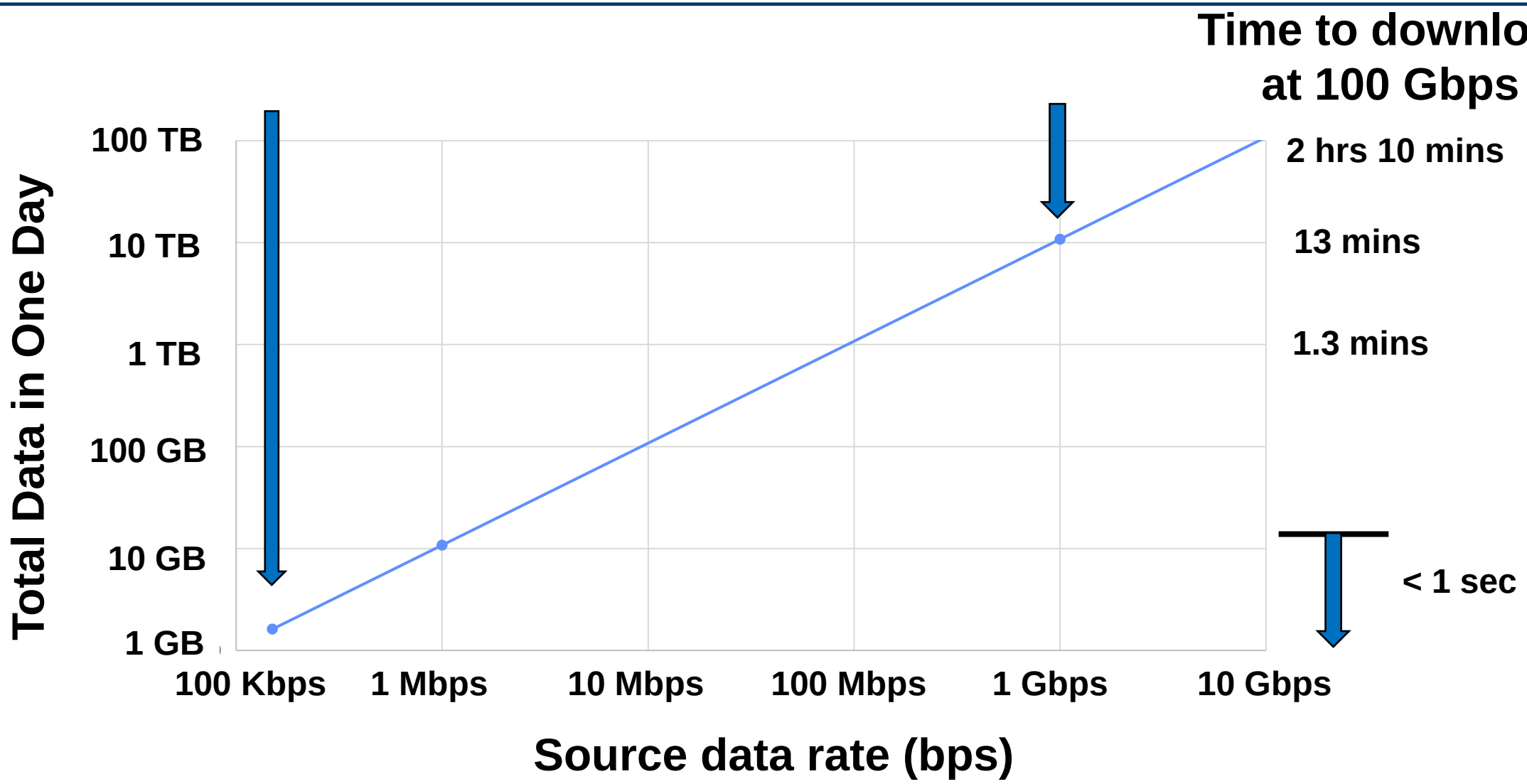
- Many options for intermittent relay/readout
  - Some balloon trajectories ultimately pass near a location where a transported terminal could be placed (can be up to few hundred km)
  - An aircraft flown as much as 1000 km from the balloon could carry a small terminal
  - A small balloon could be tethered and flown above clouds with a small terminal
  - Optical transmission to a satellite in a pLEO constellation might even be feasible

- Huge data burst rates could enable very short connections to dump even large memories

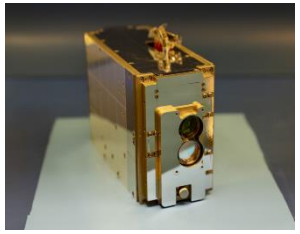
Calculation: Data Generated per Day



Calculation: Data Generated per Day



Possible Connectivities in Optical – II
Store and Forward



Terminals could be based on TBIRD

Direct downlink 10-200 Gbps

Optical Ground Station

Possible system sizing for 100 Gbps*

Range (km)	80	250	1000
Transmit aperture (cm)	2.5	2.5	2.5
Transmit power (W)	0.1	0.75	1.0
Receive aperture (cm)	2.5	2.5	7.5

*No complete off-the-shelf designs exist yet for such systems.

What Would Be Entailed for Ops With Lasercom?

1. Terminals require approximate position and attitude knowledge (for initial search of correct beam aiming) – GPS, star tracker, etc would be part of design
2. User uploads data describing link (perhaps via very low rate RF)
   - Position of other terminal
   - Time to start
3. Check alignment of ground terminal (automated)
4. Start acquisition/track protocol at prescribed time
5. Intermittent operation dealt with autonomously and in-band (ARQ, etc.)

Summary of New Possibilities with Optical Comm

- Orders of magnitude more continuous data flow when balloon only few hundred km from ground site (direct downlink, weather-dependent)
- Gbps-class streaming to GEO relays (with high-cost terminal)
- Many orders of magnitude more data via store and forward (if can wait)
  - 10-s to 100s TB memories available
  - Days to weeks of stored data from very high-data-rate sensor
  - Extremely fast bursting of data to ground- or air-based receiver when connection is possible